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STATIC PRESSURE POSITION ERROR CALIBRATION OF THE NAE T-33 C-FSKH

ÉTALONNAGE DE LA PRESSION STATIQUE DU T-33 C-FSKH DE L'ÉAN POUR DÉTERMINER L'ERREUR DE POSITION

by/par

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National Aeronautical Establishment

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SUMMARY

The static pressure position error calibration of the NAE T-33 C-FSKH is presented. This calibration, necessary for the high altitudes and Mach Numbers flown in the United States FAA Vertical Separation Study, is an expansion of earlier low altitude low speed calibrations. Data collected cover a wide range of altitudes and dynamic pressure - Mach Number combinations permitting calibration of the static pressure sources of both the aircraft noseboom and of a non-retractable Douglas Trailing Cone installation. Corrections for both sources varied linearily with dynamic pressure. Neither compressibility nor weight effects were observed for either pressure source for the speeds and weights tested. The assessed accuracy of the noseboom static pressure position error calibration was 11 feet at M = 0.70 at 35,000 feet MSL.

RÉSUMÉ

L'étalonnage de la pression statique du T-33, C-FSKH, de l'ÉAN pour déterminer l'erreur de position est présenté. Cet étalonnage, nécessaires en raison des hautes altitudes et des nombres de Mach élevés atteints dans le cadre de l'étude sur l'espacement vertical de la FAA des États-Unis, est un ajout aux étalonnages basse vitesse et basse altitude antérieurs. Les données recueillies recoupent une grande plage d'altitudes et de pression dynamique en fonction du nombre de Mach, ce qui permet d'étalonner les sources de pression statique de la flèche de nez de l'appareil et d'un cône de traînée Douglas non escamotable. Les corrections des deux sources ont varié de façon linéaire en fonction de la pression dynamique. Aucun effet de compressibilité ni de masse n'a été remarqué sur l'une ou l'autre source de pression pour les vitesses et les masses soumises aux essais. La justesse de l'étalonnage de la pression statique pour déterminer l'erreur de position était de 11 pieds pour un nombre de Mach de 0,70 à une altitude de 35 000 pieds au niveau moyen de la mer.

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1.0 INTRODUCTION

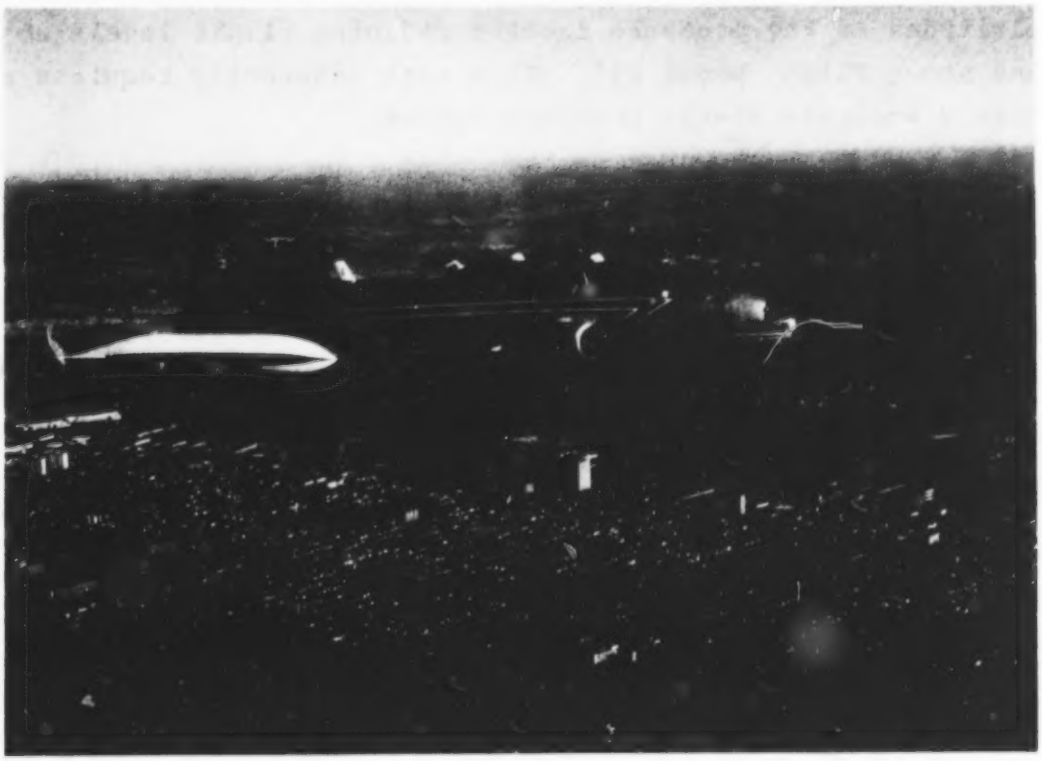
In November 1984 the National Aeronautical Establishment of the National Research Council of Canada was asked to participate in the data collection phase of the FAA Vertical Separation Project, a project coordinated with the International Civil Aviation Organization (ICAO). This participation has taken the form of the use of the NAE T-33 C-FSKH (Fig. 1) in conjunction with tracking radars, as a calibration tool for determining the actual geometric altitudes of the pressure isobars defining flight levels at and above Flight Level 290. This task inherently requires a highly accurate static pressure system.

Previous research using C-FSKH involved low altitude (below 5000 ft), moderate speed (up to 250 kt) flight and hence the aircraft's static pressure position error calibration was tailored for this regime. The Vertical Separation Project however involved higher altitudes and speeds and so required a more extensive high altitude, high speed calibration. For this reason, and to confirm the static pressure accuracy of the aircraft, a new, more comprehensive static pressure position error calibration program was planned. This program entailed two phases:

1) Low altitude (500 ft MSL) flights involving radar altimeter height measurement and trailing cone static pressure measurement.

2) High altitude flights using techniques similar to 1) but with ground based tracking radars for height measurement.

The purpose of this report is to detail the methods and results of these calibration flights. To this end the paper will first discuss the theory and procedures for the flights and will then present the results and final position error correction for the noseboom and trailing cone static pressure sources on the NAE T-33, C-FSKH.



NAE T-33 C-FSKH
FIGURE 1

2.0 THEORY

There are two main error sources possible in the measurement of static pressure from an aircraft:

1) the static pressure transducer which measures pressure at the aircraft static pressure port; and

2) the pressure field induced by the aircraft which alters the pressure at the aircraft static ports from that of the free stream.

Corrections for the first error source can be determined through laboratory calibration of the pressure transducer. C-FSKH employs a Paro-Scientific Digiquartz Model 215 L-AW-012 Serial Number 17417 pressure transducer as the project static pressure sensor. Periodic calibrations of this device since August 1983 confirm its stability by repeatedly demonstrating an RMS accuracy of 0.15 psf (0.07 mb). The second error source, position error (so named because the size of the error varies depending upon where pressure is sensed in the pressure field about the aircraft) can only be determined through flight test.

Analytical arguments can be made to show that the static pressure measured at a single point in an incompressible flow field with constant curved streamlines will differ from the static pressure at infinity by a term linear in airstream velocity squared (or dynamic pressure, P_D). Obviously in such a case the static pressure error will also be zero at zero velocity (or P_D). Since an aircraft noseboom is an attempt to model this simple scenario, initial looks at the position error data were made with a linear error model in mind.

Two possibly major sources of non-linear behaviour, (for the 1g level flight case examined here) demonstrated by flight test of other aircraft were known to be:

1) Aircraft weight effects - for the same indicated airspeed (or P_D) and altitude, different aircraft weights require different angles of attack for 1g level flight. This angle of attack change can, in some cases, significantly alter the streamline shape in the area of the static ports, thus altering the measured static pressure in a possibly non-linear manner.

2) Compressibility - at higher Mach numbers, generally above 0.5, the compressibility of the airflow may alter flow streamlines and, in transonic cases may generate local shock waves. Each of these effects could also cause significant departures from the linear position error model.

The possibility of weight and compressibility effects on position error create the need for a rather involved series of flight tests to fully characterize an aircraft position error.

To fully discern weight effects, the aircraft must be calibrated at different gross weights. Since aircraft angle of attack is proportional to the ratio of weight to dynamic pressure, the position error change due to weight change at low airspeed (or P_D) is the best indication of whether this weight effect is significant and should be investigated prior to full calibration flights at different aircraft weights.

The determination of compressibility effects on position error requires a different approach. The separation of the compressibility effect from the overall dynamic pressure related position error requires flight calibration at different combinations of Mach number and dynamic pressure. Since at any single altitude (pressure, temperature, density) Mach number and dynamic pressure are related on a one-to-one basis, this separation can only be accomplished by performing position error calibrations at several altitudes. If an altitude related difference in calibration is observed, the effect of compressibility is significant and must be determined by analytically fitting both variables (P_D and M) to the errors observed over the entire altitude range.

3.0 AIRCRAFT AND INSTRUMENTATION

A complete description of the test aircraft, the NAE T-33 C-FSKH, is given at Reference 1. Particulars described here pertain only to the trailing cone installation used in the majority of flights described in this report.

A Douglas high speed trailing cone device was attached to the top of the vertical stabilizer, (Fig. 2). Since this particular installation was non-retractable its length was chosen after reference to Douglas literature (Ref. 2) and consultation with Douglas personnel regarding installations on similar sized aircraft. A length of 70 feet (fin tip to static sleeve) was considered adequate to put the trailed static pressure sleeve behind the T-33's pressure field. The pressure differential between the trailing cone static source and the noseboom static source was measured using a

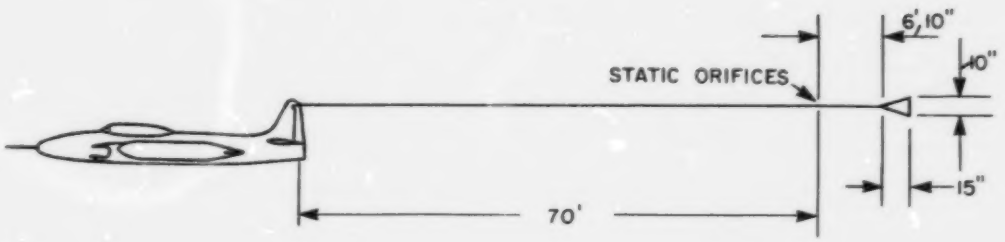


FIG. 2: TRAILING CONE INSTALLATION

Rosemount Model 1221F 1VL4B1B ±0.4 psi differential pressure transducer. Trailing cone static pressure was determined by summing noseboom and differential pressures.

All flights employing the trailing cone assembly required special non-standard ground handling techniques. In order to minimize damage while taxiing, the cone assembly was coiled and taped to either the wing or horizontal stabilizer. Once cleared for takeoff, the aircraft was positioned on the runway centreline or slightly to the upwind side. Maintenance personnel removed the assembly from the aircraft, uncoiled it and trailed it out at about 30° to the runway centreline on the downwind side. The engine was run up to military power prior to brake release and the cone was dragged off the runway behind the aircraft. On landing the aircraft was braked to a stop as quickly as possible. Just before stopping, the aircraft was turned to one side to minimize the risk of heat damage from engine

exhaust. Maintenance personnel coiled and retaped the assembly to the aircraft prior to taxiing off the runway.

The entire assembly, especially the static sleeve, was inspected for damage after each flight. Throughout the 10 flights employing the trailing cone, although the cone was observed to bounce on the runway on takeoff and drag on the runway throughout the landing roll, damage was limited to minor surface scratching to the static sleeve and trailing tube and abrasion to the trailing edge of the cone. At the end of the seventh flight a small (approximately one inch long by 1/4 inch deep) "bite" had been worn out of the trailing edge of the cone. It was replaced at that time.

4.0 PROCEDURE

For a particular flight condition (airspeed and altitude) position error is found by comparing free stream pressure at aircraft altitude with that sensed through the aircraft static ports. For these tests, free stream pressure was determined at a nominal height within 100 to 200 feet of aircraft height. Adjustment to account for the pressure differential between this nominal height and the aircraft height for a particular test point was made by:

$$P_{SFS\ a/c} = P_{SFSN} - \rho g \Delta h$$

where

$P_{SFS\ a/c}$ = free stream pressure at the aircraft height

P_{SFSN} = free stream pressure at some nominal height

ρ = air density at the nominal height

g = gravitational constant (32.17 ft/sec)

Δh = geometric height difference between the aircraft's height and the nominal height.

Free stream pressure was determined by two different methods. The first method, (Fig. 3), utilized a ground observer stationed close to the aircraft ground track. As the aircraft flew past, 100 to 200 feet above, the observer recorded static pressure and temperature at ground level. Geometric height difference between the ground observer's level and the aircraft was measured by the aircraft's radar altimeter. This method was used in some, but not all, of the low altitude cases.

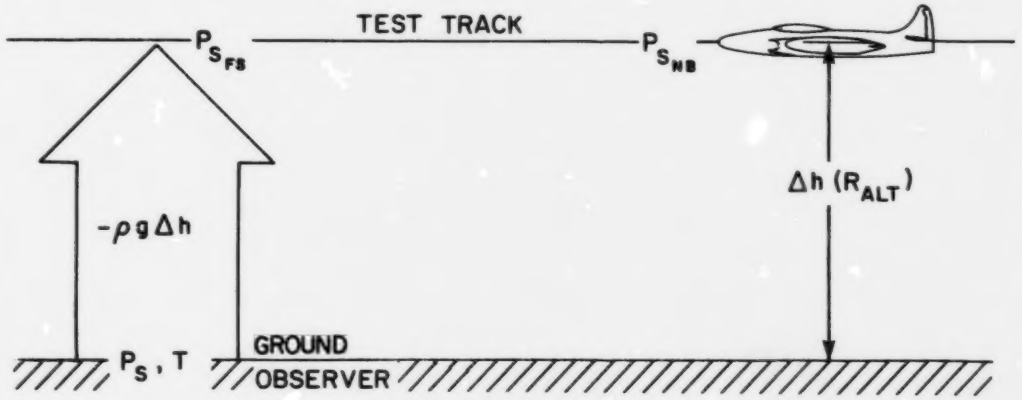


FIG. 3: POSITION ERROR CALIBRATION – GROUND OBSERVER METHOD

The second method of determining free stream static pressure, (Fig. 4), was used in all high altitude and in some low altitude cases. This method involved flying a low speed (150 KIAS) calibrating track at the nominal test altitude. Free stream pressure for the calibrating track was determined from the low altitude ground observer calibration. That calibration was considered valid for the higher altitudes because it indicated that at the altitudes

investigated neither weight nor compressibility effects would be present at 150 KIAS. In the high altitude cases the difference between the height of the calibrating track and height of subsequent higher speed tracks was determined by ground based radars. In low altitude cases this height differential was measured by the aircraft radar altimeter. In order to account for the possibility of pressure levels shifting with time, low speed tracks were flown as both first and last tracks for each altitude investigated.

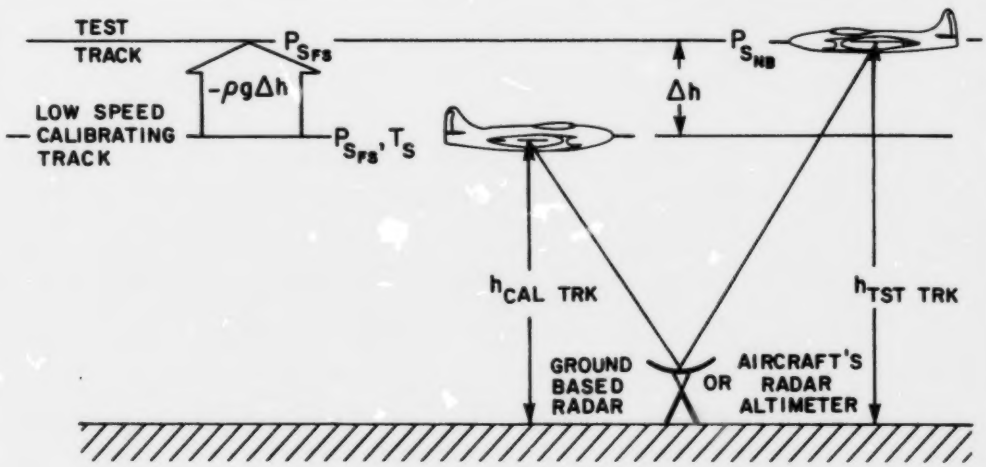


FIG. 4: POSITION ERROR CALIBRATION – CALIBRATING TRACK METHOD

A simpler method of position error calibration, and one which was also employed in these tests, is through the use of a trailing static cone. This device attempts to locate a static pressure source outside of the aircraft induced pressure field and therefore to sense directly the true free stream pressure. The difference between the aircraft static port pressure and that sensed at the trailing cone is a direct measure of the aircraft position error if the trailing cone device has no errors of its own. In order to

prove or disprove this error-free assumption and, if correct, to facilitate future calibrations, the trailing cone device was calibrated at the same time and by the same methods used for the noseboom calibration.

Table 1 lists the flights completed from which data were used in determining C-FSKH's noseboom and trailing cone static source position errors.

Mission List

Table 1

Place	Date	Missions	Remarks
Ottawa	Aug 1985	4 low altitude flights	Ground observer method. Low altitude position error data for nose boom and trailing cone.
Ottawa	Aug 1985	2 radar altimeter calibration flights	Radar altimeters calibrated using photo theodolite triangulation.
Ottawa	Jan 1986	1 radar altimeter calibration flight	Radar altimeter calibrated vs. groundspeed as above.
Wallops, Va.	Mar 1986	5 high altitude flights	Low speed calibrating track method. 15,23,29,35 & 37,000 foot data for both noseboom and trailing cone.
Ottawa	May 1986	1 low altitude flight	Low speed calibrating track method. Low altitude flight at 100 and 450 feet over water. Both noseboom and cone data taken.
Ottawa	May 1986	1 nose bay leak check flight	Low speed calibrating track method. Differential pressure line vented to nose bay.
Ottawa	Jul 1986	1 low altitude flight	Ground observer method. Low altitude position error data for noseboom only.

The August 1985 low altitude flights were made just after sunrise to ensure the best probability of calm air conditions. For each speed the aircraft was aligned with the runway at sufficient distance out to permit arriving at the threshold at stabilized speed at approximately 150 feet above the runway. The aircraft was flown down the runway in essentially level, unaccelerated flight past a ground observer who was located approximately 6,000 feet from the threshold. Low speed points were flown over a wide range of aircraft weights to try to reveal any aircraft weight effects.

The radar altimeter flights in August 1985 were carried out to calibrate the two radar altimeters used in the low altitude flights. The aircraft was flown down runway centreline at a range of geometric heights covering those used in the low altitude flights. The aircraft was tracked by phototheodolite. Geometric height above the runway was determined by triangulation. Results of these flights were used for all flights using the radar altimeter for height measurement. Radar altimeter calibration results are presented in Reference 3.

The radar altimeter flight in January 1986 was carried out to determine if the radar altimeter height calibration remained constant with aircraft ground speed. Speeds ranging from approximately 150 to 400 knots were flown at a target height of 125 ft above the runway (mid point height for the low altitude flights). Geometric height above the runway surface was determined by phototheodolite triangulation.

The five high altitude flights completed at the NASA Wallops Flight Facility at Chincoteague Island, Va., in March 1986 were carried out using the low speed calibrating track method for free stream pressure determination. Ten to fifteen nautical miles were allowed for each run for speed and altitude stabilization. Stabilized data were taken for approximately one minute for each run, including the first and last low speed calibrating track runs. Geometric height data from the height finding radars was provided to NAE by NASA. Up to three radars tracked the test aircraft for each run. Two of the radars employed beacon tracking (a special transponder was fitted to C-FSKH for these tests) and a third tracked by "skin paint". In order to minimize height errors due to possible radar diffraction problems, only high radar elevation angle data (above 45 degrees elevation) were used.

The three remaining flights carried out in May and July 1986 were flown to recheck the low altitude position error data and to attempt to resolve a difference apparent between the high and low altitude calibrations. The first of the three flights was flown duplicating as closely as possible at low altitude those tests done at higher altitude at Wallops in March 1986. Free stream pressure was determined by the low speed calibrating track method. Height data was provided by the aircraft radar altimeter. The flight took place over a 7 mile stretch of lake surface north of Ottawa.

The nose bay leak check flight was flown to determine the effects of a noseboom static pressure line leak to the aircraft nose bay. Again the radar altimeter provided height data above the lake surface. The last flight, in July 1986, was carried out at the airport at Ottawa to confirm, by the ground observer method, the final noseboom

position error correction (PEC). Techniques used in this flight were identical to those used in the August 1985 low altitude calibration flights with the exception that the trailing cone was not installed.

5.0 RESULTS AND DISCUSSION

Position error corrections for both the noseboom and trailing cone installation produced from the August 1985 low altitude calibration flights are presented in Figures 5 and 6. Linear, least squares curve fitting provides:

a) for the noseboom

$$P_{S_{TRUE}} = P_{S_{NB}} + 0.14 - 0.051\ P_{Di}$$

RMS error 0.44 psf

b) for the trailing cone

$$P_{S_{TRUE}} = P_{S_{TC}} = 0.19 - 0.007\ P_{Di}$$

RMS error 0.25 psf

The data for the noseboom installation appear linear throughout the speed range investigated. The low speed points of this data set were flown at both the beginning and end of these flights, providing data for gross weights of 15,000 lb and 11,700 lb, representing near maximum and near minimum gross weights for this aircraft configuration. These flight conditions did not measurably alter position error so weight effects are concluded to be negligible for this installation. The data also do not display any noticeable non-linear behaviour at the higher Mach numbers (up to M=0.64) investigated indicating a lack of Mach or compressibility effects. Data for the trailing cone installation are similarly linear also indicating a lack of compressibility effects.

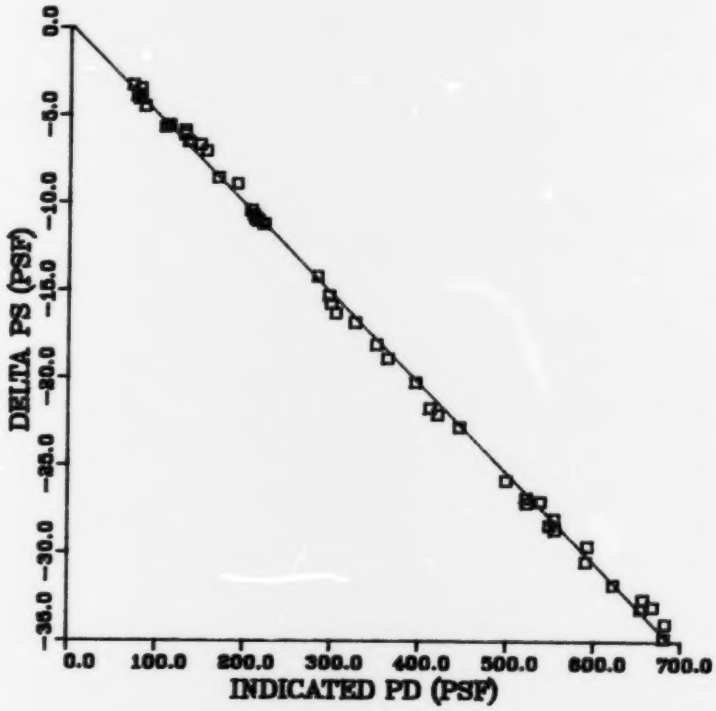


FIG. 5:

NOTES:
NOSEBOOM PEC GROUND OBSERVER METHOD AUG 85
DELTA PS : TRUE −INDICATED

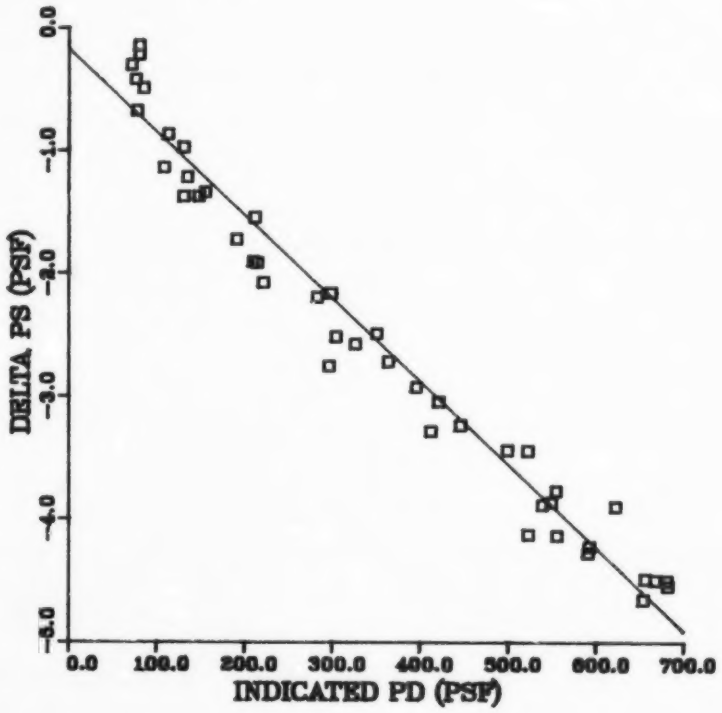


FIG. 6:

NOTES:
TRAILING CONE PEC GROUND OBSERVER METHOD AUG 85
DELTA PS : TRUE −INDICATED

Since it was expected that the trailing cone would sense correct free stream pressure, a flight was made to determine whether the radar altimeter data contained an unaccounted for speed related error which caused the observed PEC slope of 0.007. If such an error were present it would have affected the noseboom calibration as well. Results of the January 1986 radar altimeter flight, Figure 7, reveal negligible ground speed related radar altimeter error for the radar altimeter used in these tests.

Linear, least squares fits for the data sets collected during the March 1986 high altitude flights at Wallops are provided in Table 2.

Noseboom and Trailing Cone Position Error Corrections
Calibrating Track Method - March 1986
Table 2

	Noseboom			Trailing Cone		
Altitude (ft MSL)	Bias	Slope	RMS Error	Bias	Slope	RMS Error
15,000	-1.24	-0.038	0.29	-0.28	-0.008	0.37
23,000	-1.28	-0.039	0.32	-0.58	-0.007	0.37
29,000	-1.02	-0.038	0.29	-0.07	-0.007	0.28
35,000	-1.04	-0.039	0.37	-0.04	-0.008	0.39
37,000	-0.84	-0.040	0.15	+0.22	-0.009	0.16

$$P_{S_{TRUE}} = P_{S_{NB/TC}} + BIAS + SLOPE\ (P_{Di})\ psf$$

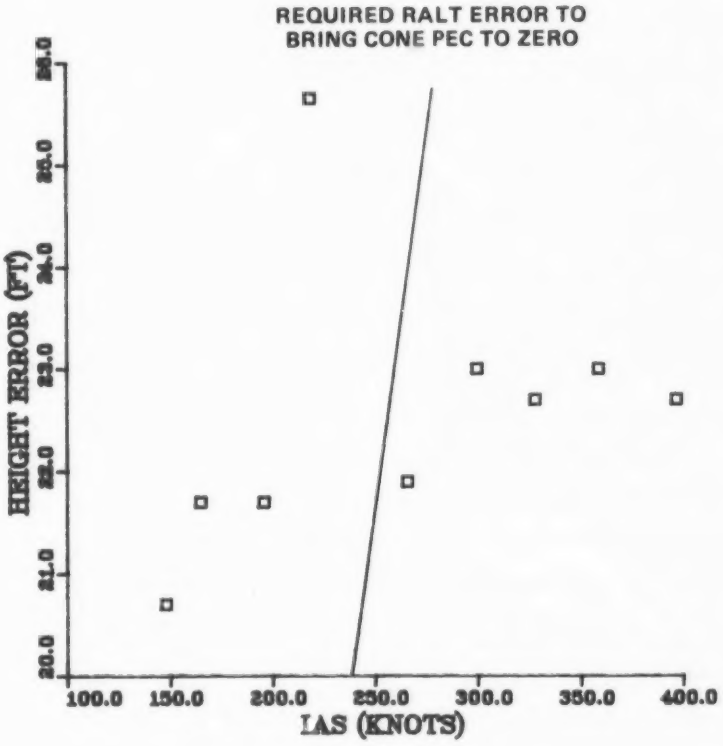


FIG. 7:

NOTES:
RADAR ALTIMETER CALIBRATION VS. AIRSPEED
HEIGHT ERROR : TRUE – INDICATED

These calibrations show negligible change for either the noseboom or trailing cone as altitude increases thus indicating a lack of sensitivity to Mach number or compressibility effects in the speed range tested (up to approximately 0.72 Mach number, all altitudes). From the high altitude flights then, position errors for both noseboom and trailing cone can be represented as linear functions of dynamic pressure alone. Data for all five altitudes are combined and presented as Figures 8 and 9. Linear, least squares fitting of the combined data yields:

(a) for the noseboom

$$P_{S_{TRUE}} = P_{S_{NB}} - 0.909 - 0.040\ P_{Di}$$

RMS error 0.25 psf

(b) for the trailing cone

$$P_{S_{TRUE}} = P_{S_{TC}} + 0.13 - 0.009\ P_{Di}$$

RMS error 0.27 psf

These two position error calibrations differ in slope value from the August 1985 calibrations. The trailing cone slope change can be explained by the fact that it is essentially within the error band of the measured data. The noseboom slope change, however, is well outside that error band. Since the high altitude calibrations prove that no Mach number effect is present, the data for all altitudes should conform to the same linear fit. The discrepancy in error slope suggests that one of the data sets, either the March 1986 or August 1985 set, contains an unaccounted for error source. If the August 1985 data were in error, the position error used to determine free stream pressure for the low speed calibrating tracks in the high altitude flights would also be in error. This would have introduced a bias error into the high altitude calibrations, but it would not have affected their slopes.

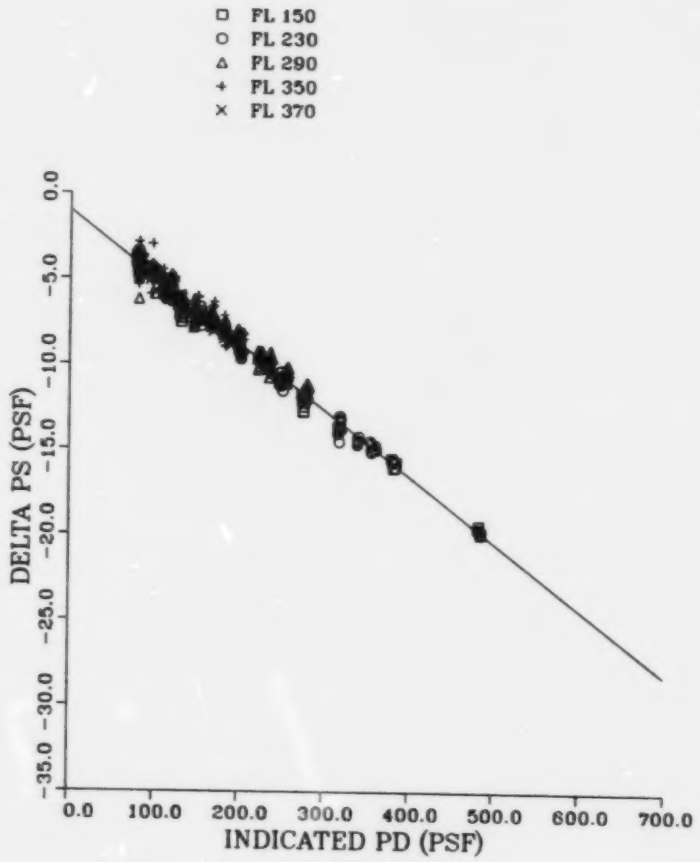


FIG. 8

NOTES:
NOSEBOOM PEC WALLOPS MAR 86
DELTA PS : TRUE – INDICATED

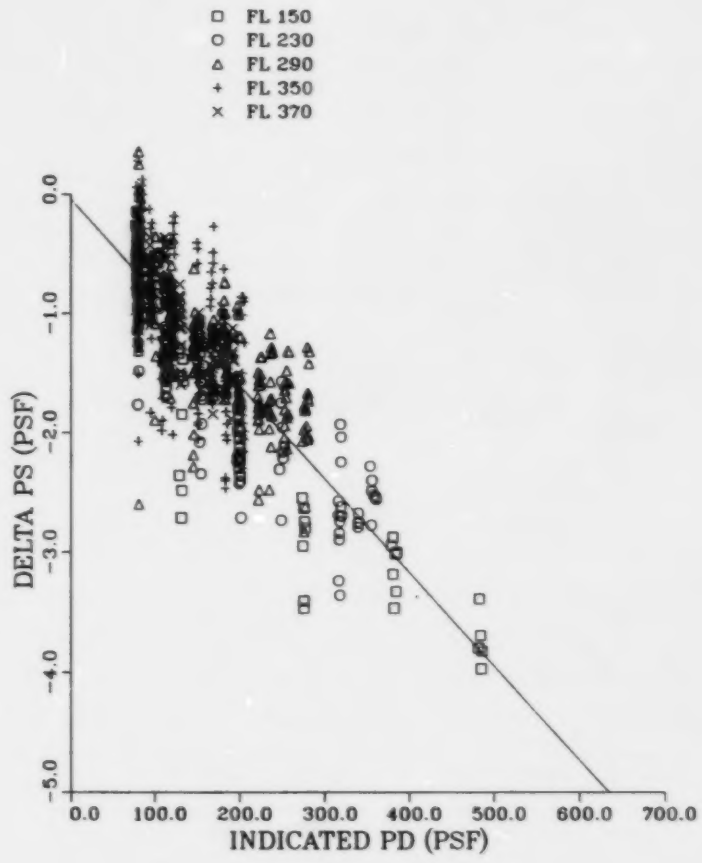


FIG. 9

NOTES:
TRAILING CONE PEC WALLOPS MAR 86
DELTA PS : TRUE – INDICATED

In searching for an explanation for the different noseboom position error slopes, several possibilities were explored:

a) a bent noseboom causing static pressure to be sensed in a different position in the aircraft flow field;

b) differences between low and high altitude data reduction software;

c) low altitude ground effect;

d) pressure capsule calibration changes;

e) NASA radar groundspeed related height measurement errors;

f) system pressure leaks.

In examining the possibility of a bent noseboom, besides inspecting the noseboom itself and not finding evidence to support or refute a bend, data from the ongoing FAA Vertical Separation Project (referred to in the Introduction) were examined. Numerous flights before, between, and after the August 1985 and March 1986 calibrations had been flown in support of this study. During these survey flights the aircraft was flown daily at altitudes ranging from FL 290 through FL 410 on level survey legs approximately 8 to 10 minutes long. The aircraft altimeter system (completely independent of the noseboom system) was used as the reference for altitude station keeping. Assuming the aircraft system was unchanged over the period then for any given leg speed (differences could change with speed) survey legs before and after any possible bend would have been flown at the same average free stream pressure (same aircraft altimeter indication). If the shift

in slopes were due to a bend then at some time between August 1985 and March 1986 a shift in average recorded altitudes (noseboom static pressure) would appear in the survey data.

At FL 350 and 190 psf dynamic pressure (approximately M = 0.7) the different slopes (0.051 and 0.040) account for an approximate 2.1 psf static pressure decrease (or a 90 foot upward shift in altitude) sensed by the nose boom. In other words, data recorded after a bend should have shown an average altitude increase of 90 feet. FL 350 data for survey flights before, between and after the calibration flights are presented as Figure 10. As can be seen, no significant shift occurred. Therefore, since it is very unlikely that the aircraft system was altered in an exactly similar fashion at the same time (which would account for there not being a change in the FAA survey data) it is concluded that static pressure sensed at the noseboom did not change and therefore a noseboom bend could not have been responsible for the slope change.

Differences in data reduction routines employed for the ground observer and low speed calibrating track methods were examined. Although no apparent differences which would account for the slope change were found, the August 1985 (ground observer method) data was rerun using the low speed calibrating track method software. The results did not change: the August 1985 slope remained 0.051. Data reduction differences were then excluded as a possible source of the change in slope.

Based on the possibility that the August 1985 data flown at 100 to 150 feet above a runway surface might have been contaminated by some residual ground effect, a low

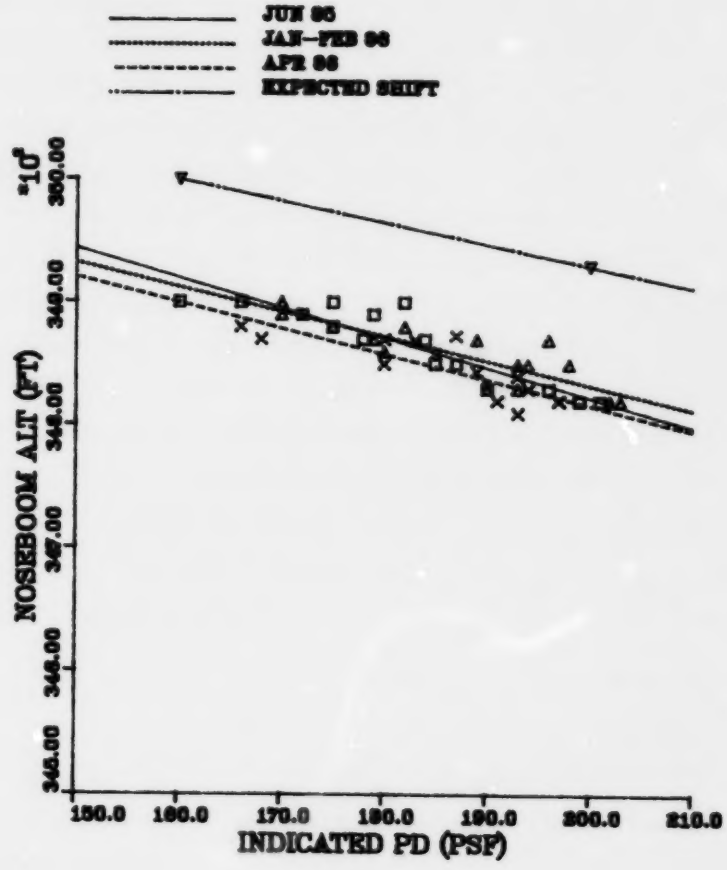


FIG. 10:

NOTES:
AVERAGE RECORDED NOSEBOOM ALTITUDES FOR FL 350
FAA SURVEY LEGS JUN 85 TO APR 86

altitude flight was made in May 1986. The flight was made over a lake surface which ensured a level non-sloping surface for radar altimeter height measurement and, in addition, permitted a minimum of 45 seconds or more stabilization time for each run. Test speeds from 150 to 335 KIAS (80 to 400 psf P_D) were flown at 100 and again at 450 feet above the lake surface. Data were reduced using the August 1985 calibration to determine free stream pressure for the low speed tracks. Data from this flight is presented as Figures 11 and 12. Figure 11, the noseboom position error correction, shows no apparent slope difference between the 100 and 450 foot data, supporting the conclusion that, for this installation, ground effect does not alter position errors at altitudes as low as 100 feet AGL and therefore could not have contaminated the August 1985 data. Linear, least squares fit for this data (100 and 450 foot data combined) is as follows:

a) for the noseboom

$$P_{S_{TRUE}} = P_{S_{NB}} - 0.97 - 0.041\ P_{Di}$$

RMS error 0.36 psf

b) for the trailing cone

$$PS_{TRUE} = P_{S_{TC}} - 0.19 - 0.010\ P_{Di}$$

RMS error 0.34 psf

Again it should be remembered that an incorrect free stream pressure for the slow speed calibrating tracks would affect the bias term above, but not the slope. Based on close agreement with the March 1986 high altitude slope (0.040) the August 1985 calibration became highly suspect.

Pressure capsule laboratory calibrations were examined for possible shifts which might not have been accounted for in the data. Calibrations from July 1985 through to July

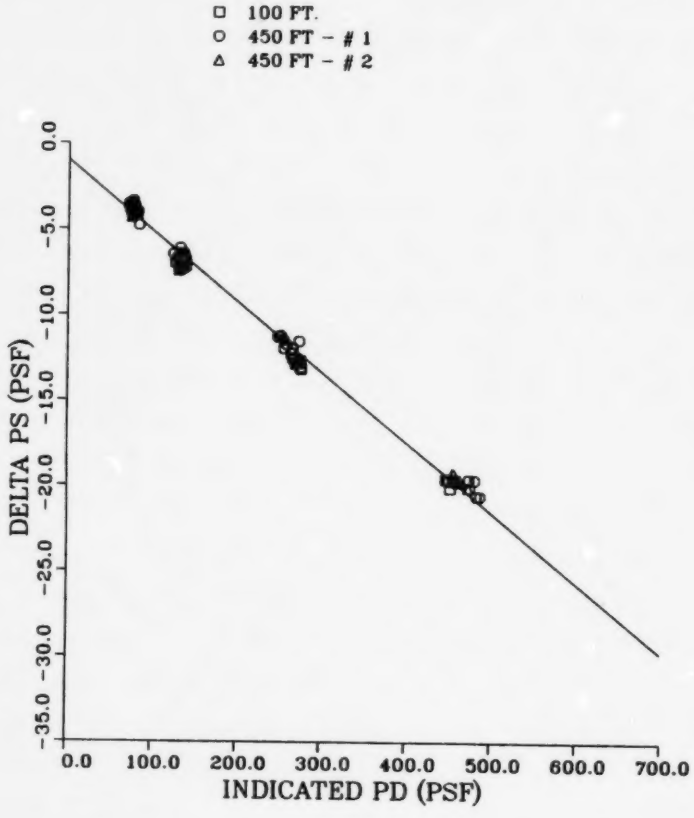


FIG. 11

NOTES:
NOSEBOOM PEC LAC DESCHENES MAR 86
DELTA PS : TRUE – INDICATED

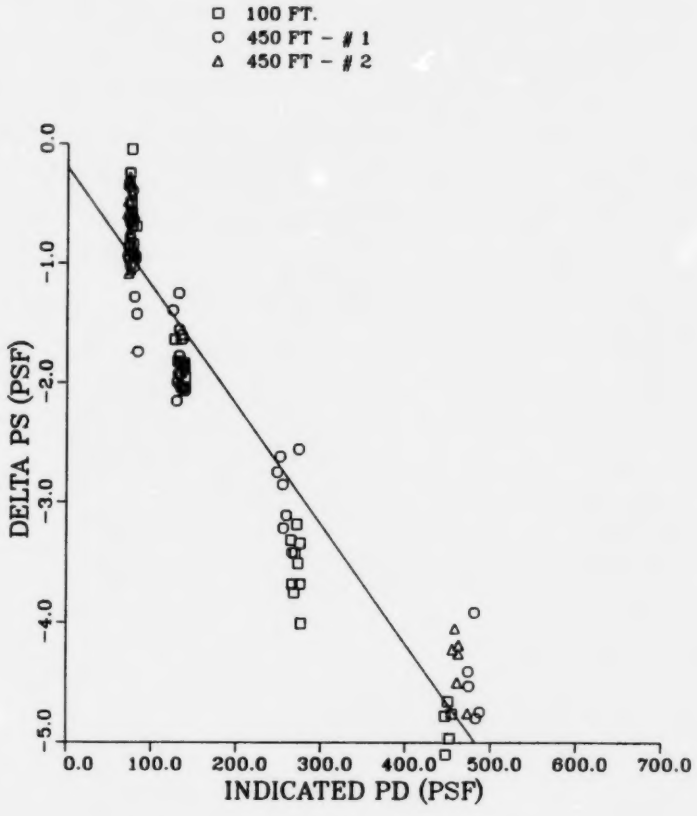


FIG. 12

NOTES:
TRAILING CONE PEC LAC DESCHENES FLIGHT MAR 86
DELTA PS : TRUE – INDICATED

1986 were reviewed and the calibrations remained essentially identical throughout the period. In addition, since capsule calibrations were applied to the FAA survey data, an incorrect calibration would have appeared there as an altitude shift. As mentioned earlier, none was apparent. It was concluded that unaccounted for changes in pressure capsule calibrations were not the cause of the change in slope.

Since the difference between the two position error calibrations varied with speed, the possibility that the NASA radar height calculations might have been affected by the aircraft ground speed was examined. However, the May 1986 low altitude flight, using the aircraft radar altimeter (which was by now known not to have a speed related error) for height measurement, confirmed the same 0.040 P_D slope. Also, if there were a ground speed related error in the NASA ground based radar data then the combination of the pattern flown (reversing direction with each increase in speed) and upper level winds would have caused a "ratchet" effect in the radar height data which would have resulted in large RMS error values. As can be seen from Table 2 this was not the case. Speed related height measurement errors in the NASA radar data were concluded not to be responsible for the slope change.

The last possibility explored was that of a leak in the pressure tubing to the two pressure capsules (absolute and differential pressure transducers). All joints in the pressure tubing connections had been tested for leaks except for the two connections at the differential transducer which measured the difference between noseboom and trailing cone pressures. The narrow differential pressure capability of this transducer made it impractical to pressure test the

entire system without overpressurizing and damaging this transducer. Instead, static pressure lines were capped at the differential transducer and pressure checked in two sections. These checks had revealed no leaks. The lines were then reconnected to the differential transducer and the tests were flown assuming all connections were tight enough to eliminate any leaks.

Attention was focused on the noseboom pressure connection at the differential transducer. If a leak were present here the static pressure transducer would be exposed to a combination of noseboom and nosebay pressures. The question remaining was which way would such a leak affect the recorded noseboom pressure? In order to answer this question a nosebay leak check flight was made.

For this flight the difference in pressure between the noseboom and nosebay was sensed by the differential pressure transducer. Actual nosebay pressure was then calculated by the addition of the measured differential to the measured noseboom static pressure. Data were recorded throughout a speed range of 150 to 362 KIAS (80 to 477 psf P_D). Flight data were processed using the calibrating track data reduction software. The following linear, least squares fit (neglecting the bias term) describes the aircraft nosebay position error:

$$P_{S_{TRUE}} = P_{S_{NBay}} - 0.092\ P_{Di}$$

Since this error slope is in the same sense and is larger than the noseboom term, a noseboom line leak to the nosebay would cause the slope term of the resulting position error calibration to increase in magnitude. It is reasonable to assume that a leak of smaller proportions, for example a

partially tightened connection, would cause a similar direction but smaller magnitude shift. A small leak then would explain a shift in slope from 0.040 to 0.051 in the August 1985 data, suggesting the possibility of a leak being present during the August 1985 tests.

A review of previous position error calibrations (done without a trailing cone installation) for this aircraft-noseboom installation tends to support the theory that the 0.04 slope is correct. The most recent calibration previous to these tests was in April 1984 (low altitude, ground observer method); the slope at that time was 0.041 P_{Di}.

A final low altitude flight was made in July 1986 to re-establish by the ground observer method the noseboom position error calibration. A speed range of 150 to 290 KIAS (approximately 80 to 300 psf P_D) was flown. Position error data for this flight are presented as Figure 13. A linear, least squares data fit provides the following:

$$P_{S_{TRUE}} = P_{S_{NB}} - 0.040\ P_D$$

RMS error 0.17 psf

The small amount of scatter and negligible bias in the data support the theory that the error is linear with P_D and should pass through zero at zero airspeed. The error slope is in close agreement with all other calibration flights described herein with the exception of the August 1985 data, further supporting the view that something, possibly a leak, adversely affected the August 1985 data.

Data from the Wallops (March 1986) high altitude and the May 1986 low altitude flights were reassessed using theabove position error calibration to determine free stream

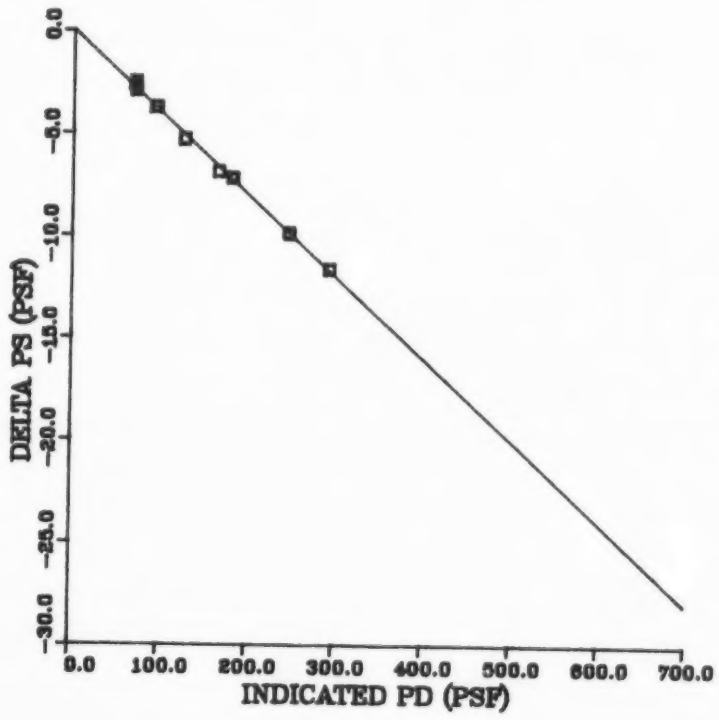


FIG. 13:

NOTES:
NOSEBOOM PEC GROUND OBSERVER METHOD 28 JUL 86
DELTA PS : TRUE – INDICATED

pressure for the low speed calibrating tracks. Combining these data sets provides the following final position error calibration for the noseboom static source on C-FSKH:

$$P_{S_{TRUE}} = P_{S_{NB}} - .13 - 0.039\ P_{Di}$$

RMS error .26 psf

and, for the trailing cone installation:

$$P_{S_{TRUE}} = P_{S_{TC}} + .80 - 0.008\ P_{Di}$$

RMS error .29 psf

It should be pointed out that the above trailing cone position error calibration is specific to the installation of the cone on C-FSKH. The trailing cone position error is due most probably to either residual aircraft pressure field effects (incorrect cone trail length) or pressure field effects due to the cone and static sleeve assembly itself. This correction makes it apparent that if the trailing cone method had been used by itself (making the assumption that the cone had no errors) to provide the position error correction for C-FSKH, a slope error of approximately 0.01 P_D would result, causing the cone produced noseboom position error to have a slope of -0.030. This error in calibration is equivalent to a height error of approximately 80 feet when the aircraft is flying at 0.7 Mach number at 35,000 feet MSL.

6.0 CONCLUSIONS

- Noseboom position error is unaffected by weight changes throughout the weight/speed range investigated (11,700 lb to 15,000 lb, 150 KIAS to M = 0.72).

- Noseboom and trailing cone installations did not demonstrate noticeable Mach effects up to M = 0.72.

- Position errors for the noseboom and trailing cone installations vary linearly with dynamic pressure.

- The noseboom position error calibration provided in Reference 1 is invalid, most probably due to system pressure leaks.

- The position error calibraton for the noseboom installation for the NAE T-33 C-FSKH, valid for all altitudes, for weights of 11,700 lb to 15,000 lb, and for speeds from 150 KIAS to M = 0.72, is:

$$P_{S_{TRUE}} = P_{S_{NB}} - .13 - 0.039\ P_{Di}\ \text{psf}$$

RMS error .26 psf

- The trailing cone installation on C-FSKH demonstrated a position error. This error, valid for all altitudes and speeds from 150 KIAS to M = 0.72, is:

$$P_{S_{TRUE}} = P_{S_{TC}} + 0.80 - .008\ P_{Di}\ \text{psf}$$

RMS error .29 psf

- Based on the RMS error demonstrated in the above noseboom position error calibration, static pressure data recorded from the noseboom source of C-FSKH flying at M = 0.70 at FL 350 has a pressure altitude accuracy of 11 feet, RMS.

7.0 REFERENCES

1. Baillie, S.W. — A Description of the NAE T-33 Turbulence Research Aircraft (NTRA) LTR-FR-90, April 1984.

2. — Trailing Cone Systems Applications, Douglas Technical Memorandum, 17 Jan. 1967 revised 7 Aug. 1967.

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DESCRIPTORS (KEY WORDS)/MOTS-CLÉS
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1. Static pressure
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SUMMARY/SOMMAIRE

The static pressure position error calibration of the NAE T-33 C-FSKH is presented. This calibration, necessary for the high altitudes and Mach Numbers flown in the United States FAA Vertical Separation Study, is an expansion of earlier low altitude low speed calibrations. Data collected cover a wide range of altitudes and dynamic pressure – Mach Number combinations permitting calibration of the static pressure sources of both the aircraft noseboom and of a non-retractable Douglas Trailing Cone installation. Corrections for both sources varied linearily with dynamic pressure. Neither compressibility nor weight effects were observed for either pressure source for the speeds and weights tested. The assessed accuracy of the noseboom static pressure position error calibration was 11 feet at M = 0.70 at 35,000 feet MSL.

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